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CONSTANT FALSE ALARM RATE (CFAR) AUTOTREND EVALUATION REPORT

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13. ABSTRACT *(Maximum 200 Words)*

A collaborative program was successfully conducted by Humaware and the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) (managed by U.S. Army International Technology Center-Atlantic (USAITC-A)) between October 2010 and February 2011 to assess the performance of the Constant False Alarm Rate (CFAR) Autotrend dynamic alert detection technology as an augmentation to the Apache Modernized Signal Processor Unit (MSPU) fault detection technology. After an initial setup and optimization of the processing parameters, these results were achieved with a single set of parameters to control the CFAR and Autotrend processing, indicating a robustness that should result in a low overhead for data management. The evaluation data set contained events for all Condition Indicators (CIs) and for a large number of modules for the MSPU equipped AH-64D Apache helicopter. There was one set of CIs for the Auxiliary Power Unit (APU) that clearly indicated significant data quality issues, and these are being investigated by the Army.

The principal findings of the assessment are that the CFAR Autotrend technology—

- Exceeds the fixed threshold detection accuracy.
- Provides a significantly earlier detection than the fixed thresholds.
- Detects maintenance events (material faults) that are not identified by fixed thresholds.
- Is ready for use as an engineering tool in its current form.

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EXECUTIVE SUMMARY

A collaborative program was successfully conducted by Humaware and the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) (managed by U.S. Army International Technology Center-Atlantic (USAITC-A)) between October 2010 and February 2011 to assess the performance of the Constant False Alarm Rate (CFAR) Autotrend dynamic alert detection technology as an augmentation to the Apache Modernized Signal Processor Unit (MSPU) fault detection technology.

After an initial set up and optimization of the processing parameters, these results were achieved with a single set of parameters to control the CFAR and Autotrend processing, indicating a robustness that should result in a low overhead for data management.

The evaluation data set contained events for all Condition Indicators (CIs) and for a large number of modules for the MSPU-equipped AH-64D Apache helicopter. There was one set of CIs for the Auxiliary Power Unit (APU) that clearly indicated significant data quality issues, and these are being investigated by the Army.

The principal findings of the assessment are that the CFAR Autotrend technology—

- Exceeds the fixed threshold detection accuracy.
- Provides a significantly earlier detection than the fixed thresholds.
- Detects maintenance events (material faults) that are not identified by fixed thresholds.
- Is ready for use as an engineering tool in its current form.

The performance was verified as well as Component Removal and Repair/Overhaul Records (DA Form 2410) permitted and the metrics were produced and verified in accordance with ADS-79B, as in Reference 3.

The key results for the maintenance events are in the following table.

Summary of Results

Metric	Fixed Threshold	CFAR Autotrend Best Case	CFAR Autotrend Worst Case
True Positives (TP)	9	37	33
False Positives (FP)	1	0	4
False Negatives (FN)	27	0	0

(*The best and worst cases are produced by assigning the unresolved detections to be True Positive (TP)—Best Case or False Positive (FP)—Worst Case.*)

The high rate of False Negatives (FN) in the fixed threshold results demonstrate that the compromise between FP and TP embodied in simple thresholding technique is not present in the CFAR Autotrend detections. While the FN rate has not been proven for CFAR Autotrend by this

trial, there is clear potential for the detections to be verifiably reliable enough for certifying maintenance credits.

The same results expressed as raw individual detection rates that make up the maintenance events for CFAR Autotrend are in the following table.

Summary of FP Rate

Metric	Best Case	Worst Case
TP	378	367
FP	5	33
Percent of FP	8	11

This FP rate is within the target set by ADS-79B. In all cases, the CFAR Autotrend detections occurred before fixed threshold detections, as quantified in the following table.

Summary of Time to Detection

	CFAR	Autotrend
Data Points	-17	-18
Time (days)	-27	-15

Summary of time to detection is a key result demonstrating the potential for the prognostics capability envisioned for the CBM+ program.

There is evidence to show that the techniques are sensitive enough to detect incipient defects and provide the opportunity to calibrate the detection so as to discriminate between wear and faults that compromise airworthiness. Accuracy, identifiability, and separability should all be improved.

The Army has optimized a set of fixed thresholds for the AH-64D helicopter. The CFAR Autotrend has a capability to retain these thresholds as “red” alerts, and the dynamic thresholding can replace the current fixed “yellow” thresholds. The CFAR Autotrend processing also has a feature that allows fixed thresholds to be used during the initial flights following maintenance to provide detection for defects present on installation.

AMRDEC conducted an independent evaluation of the results to verify the performance and determine whether or not the software could be utilized independently of the contractor by the Army.

The chief finding is that the CFAR Autotrend technology is ready for use as an engineering tool in its current form.

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I. INTRODUCTION

The U.S. Army has performed a cooperative project with Humaware to assess the effectiveness of the Constant False Alarm Rate (CFAR) Autotrend technology in correct and early identification of faults as diagnosed by validated Condition Indicator (CI) streams from the Apache Modernized Signal Processor Unit (MSPU), a Digital Source Collector (DSC) for aircraft health data [1, 2]. This assessment was performed with participation of the technology developer.

The objective of utilizing the CFAR Autotrend technology on MSPU data is to offer an enhanced defect detection capability; that is, improved True Positive (TP), True Negative (TN), and False Positive (FP) metrics when compared to the MSPU static (fixed) thresholding technique.

The benefits of the CFAR Autotrend event detection technology are:

- Automatic processing:
  - Fewer resources required to manage the data
  - Resources concentrated on diagnostics, not data management
  - 100 percent alert detection of all CIs
- Very low False Alarm Rate (FAR):
  - ADS-79B compliant FAR of better than 10 percent of true alerts [3]
  - Many more valid alerts than false alerts
- Controlled alert rate:
  - Only alerts that lead to actionable maintenance reported
  - Manage work load in reviewing alerts to support the diagnostic processes and also manage the thresholding verification process
- Information on trends in data—Turning point in trend identified
- Improved sensitivity to defects—Earlier warning of unscheduled maintenance
- Switch On-Stay On characteristics provide more robust inputs into an automated diagnostics process which leads to more reliable diagnostics
- Can be integrated with traditional (static) alert thresholds set by the design authority

The CFAR Autotrend technology reports relative changes, or trends, in the CI data streams. The technology replaces the “warning” alert levels in the current threshold management system for the MSPU Health and Usage Monitoring System (HUMS) data, but not the alarm levels set in manuals or by the design authority. For the warning alerts, the technology reconciles the trade-off between the Probability of Detection (PD) and FAR without compromising either—something that cannot be achieved with static thresholds.

A comprehensive set of management features means that the alert rate, and more importantly, the FP rate can be controlled. This provides reliable, robust alerts for diagnostics and enough sensitivity to provide meaningful prognostics. The features ensure that scarce HUMS resources are concentrated on diagnostics, not data management.

An evaluation of CFAR Autotrend was undertaken by Humaware and the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) under a Cooperation Agreement (No. W911NF-10-2-0085), "CFAR – Auto-trend Dynamic Alert Technology Desk Top Demonstrator for AH-64 MSPU Data Plus Support for Liaison with MoD for the Exchange of CH-47 GenHUMS Data," as outlined in the following discussion.

II. DISCUSSION

A. Potential Impact on U.S. Army CBM+ System

Throughout the history of the U.S. Army CBM+ program, static thresholds have been used to define caution and alert exceedence levels for vibration-based diagnostics. It has been well demonstrated that these levels can be inadequate for differentiating between faulted and healthy populations [4]. Separability confidence, one of the four key attributes of vibration diagnostics defined by ADS-79B, must be achieved by the vibration diagnostics for successful implementation [3].

Good separability results in faulted populations that are easy to distinguish from the fleet to be identified for maintenance activity. The ADS-79B requirements for separability state that the FP rate shall be less than 10 percent depending on the criticality of the failure [3]. The acceptable False Negative (FN) rate shall be 10^{-6} depending on the criticality of the failure. The Army is evaluating CFAR Autotrend to determine if its suite of algorithms will improve the FP and FN rates of the built-in diagnostics on the MSPU, and will potentially extend the technology to improve on the diagnostics included in all the DSCs installed on aircraft.

The result of implementing CFAR Autotrend is, therefore, twofold. First, it will improve diagnostics that do not respond well to static thresholds, and second, it will allow for a transition to better understanding of remaining useful life which leads into vibration-based prognostics. A 2010 paper, authored by Wade and others, demonstrated that traditional vibration-based gear CIs exhibit significant overlap between healthy and faulted populations, and therefore the promises of CFAR Autotrend could increase the effectiveness of the onboard software significantly [5].

B. Scope of Evaluation

The Army has assembled a sample data set for this evaluation that includes a total of 29 AH-64 aircraft. The aircraft are further subdivided into 5 64A and 24 64D model aircraft. Included in the data set are known TP, TN, and FP indications that resulted in component teardown analyses. Prior to beginning the evaluation, the Army did not know that CFAR Autotrend requires a minimum length of data prior to component failure in order to identify anomalies. Seven of the cases intended to demonstrate CFAR Autotrend's ability to distinguish between healthy and faulted data did not have the required number of data points prior to component removal.

C. Evaluation Methodology

The evaluation methodology corresponds to that described in ADS-79B for Detection Algorithm Development (DAD) which summarized and agreed with the project team, as follows [3]:

- For the ground truth data set, achieve early detection when compared to the MSPU data without degrading current diagnostic accuracy, identifiability, detectability; utilize the "batting average" method on the Army's AeroWiki page for ground truth data.
- Quantify the difference in the detection times between the CFAR Autotrend and the optimized classic fixed thresholds for the ground truth data set.
- Show CFAR Autotrend correctly identifies features not part of ground truth.
    - Verify by referencing the maintenance actions reported in the DA Form 2410 and tear down reports where available.
    - Identify trend or level events not verifiable in the available ground truth data.

ADS-79B identified performance targets of 10 percent for FP and FN alarms are accepted as the target performance metrics.

D. Program Description

The objective of the program was to provide a desktop demonstrator of the CFAR Autotrend automatic dynamic alert generation technology for AMRDEC technical staff and then collaborate to evaluate the technology's features and performance.

The CFAR Autotrend Software Evaluation Program was defined by a Performance Agreement, as outlined in the following:

- 0 to 3 months:
    - Both parties agree on specifications of a demonstration data set for acceptance test (by way of email exchange). AMRDEC will supply the AH-64 MSPU demonstration data set to Humaware (by way of the USAITC-A cooperative agreement manager).
    - Humaware will analyze demonstration data set and set up the CFAR-Autotrend processing parameters at home United Kingdom (UK) location.
    - Humaware will install, set to work, and conduct acceptance test in Huntsville.
    - Humaware will provide training, and both will agree on success metrics in Huntsville.

- 3 to 6 months:
    - Humaware will provide 3 months support by way of the Internet.
    - AMRDEC will conduct independent evaluation of the software and provide progress reports by way of the Internet (monthly)
- At 6 months: Both will conduct an evaluation review meeting in Huntsville.
- 6 to 9 months: Humaware will write a report analyzing the variances of AMRDEC evaluation results and agreed standards (completed as part of 6).

The period of performance began in October 2010. The preliminary results with the Connector and Autotrend software with user documentation were delivered in December 2010.

AMRDEC provided Humaware with an example MSPU download that was used to develop the connector software and for software acceptance purposes. AMRDEC generated the evaluation data set and forwarded it to Humaware. AMRDEC and Humaware cooperated to identify the components of the data set, and Humaware produced a connector to enable the CFAR Autotrend to access and process the data and report the results.

The evaluation data set was provided by AMRDEC and Humaware using the connector software and produced a preliminary evaluation fixed database of MSPU data. Humaware then defined a preliminary set of parameters that controlled the CFAR Autotrend processing.

In December 2010, the Connector and Autotrend software were installed and accepted at AMRDEC in Huntsville. The software was used to train AMRDEC engineers on the use of the technology and form the basis of the performance evaluation.

During the December 2010 meeting, Humaware and AMRDEC agreed to the performance metrics and the performance standards to be met for the evaluation. Humaware and AMRDEC then conducted the performance evaluation in accordance with the agreed criteria.

Humaware optimized the parameter settings for the fixed database to maximize the sensitivity to defects, minimize the FN rate, and minimize the FP rate.

An evaluation was conducted comparing the CFAR Autotrend results with the DA Form 2410 reports, where available, in Huntsville, and the preliminary results were reported. It was clear that the CFAR Autotrend was detecting other events. These were identified and compared to the DA Form 2410 data and reported.

After the same software was used for the independent AMRDEC evaluation, a review meeting was held and the results were reported at a final review meeting on 11 February 2011 to assess the performance of the technology and software in meeting the U.S. Army's requirements for dynamic alert processing.

E. Preparation of the Evaluation Data

Humaware developed a software connector to download the data set from the Comma-Separated Values (CSV) files provided by AMRDEC into an Excel workbook to enable the data to be inspected. A connector was written to interface the workbook to the CFAR Autotrend processor.

AMRDEC provided a data specification to enable the data sets to be identified and filtered for analysis (workbook: AH-64D definitions Dan Wade Edit KP l final+1+reference.xls). In order to provide an ability to filter the data, Humaware provided an extension to the decode connector so that the CI Identity (ID) field could be decomposed into Component, Sensor, and CI-type. The reporting field types became Aircraft Type, Tail number, Regime, Module, CI-ID, Component, Sensor, and CI.

F. Optimization of Parameters

The CFAR and Autotrend software uses control parameters to optimize the detection performance. The parameters are defined in terms of relatively identifiable features of the data streams and do not require specialized mathematical knowledge to utilize.

For the CFAR processing, the parameters are Param Name, Separation, Maximum Car Length, Box Length, Trend in Noise (TiN) tolerance (percent), M, and N.

The Primary Threshold Exceedance (PTE) percent and Window length controls the primary threshold level and hence the sensitivity of the alerts to defects. This sensitivity can be reduced, if required, by setting the conservatism factor.

The FAR is controlled by setting the “M” and “N” factors for the M-out-of-N (MooN) processing. To predict the resulting FAR, there is a FAR calculator, as shown in Figure 1.

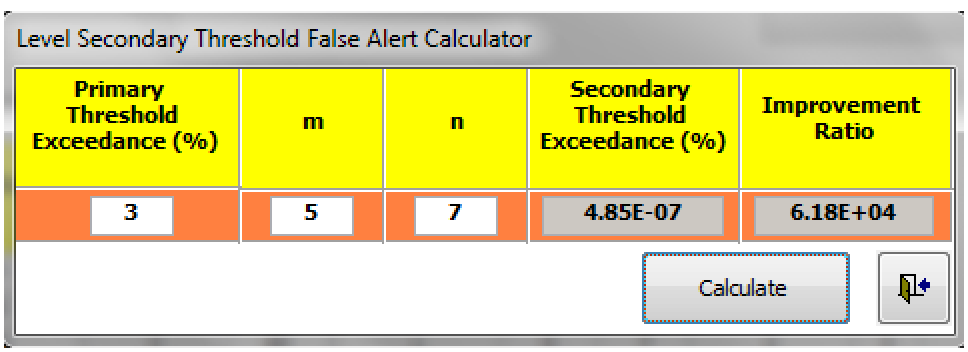

Figure 1. False Alert Calculator

This calculator determines whether or not a target FAR is achieved. It is also possible to set parameters that determine whether the level change is large enough in amplitude to be a discontinuity or a step change.

The Autotrend process is controlled by Separation, Maximum Car Length, Box Length, TiN Tolerance (percent), M, and N parameters.

The Box and Maximum Car lengths determine the length of trends that are detected. When the trend is detected, it is controlled by the Separation parameter. The TiN Tolerance and M and N factors are used to determine that only significant and sustained trends are alerted. This ensures that the FAR for Autotrend is similar to the CFAR rate.

The procedures for optimization of these parameters are contained in Reference 6, and details of the functionality can be found in Reference 1.

Initially, to establish a basic parameter set, a small sample of the data was analyzed by Humaware using the CFAR Autotrend analysis facilities. This parameter set was then applied to the fixed evaluation database with the results reported in Table 1.

Table 1. CFAR Autotrend Total Finds

Metric	CFAR Autotrend
TP	480
FP	123
Uncertain	165
Invalid Data	54
Total	822

The TP results for the CFAR processing are reported in Table 1. Examples shown in Figure 1 demonstrate that the primary threshold can track rising (first chart) or falling (second chart) data streams and are not confused by random peaks in the data. When the alert is indicated, the indication remains set despite some drop-outs in the data. The large number of threshold value changes in the charts demonstrates the requirement for the CFAR dynamic threshold setting functionality.

Figure 2 shows that the Auotrend processing can accurately identify trends and their turning points, and that the processing is not confused by other types of events, such as level changes or shallow trends that are not diagnostically useful, as shown in Figure 3.

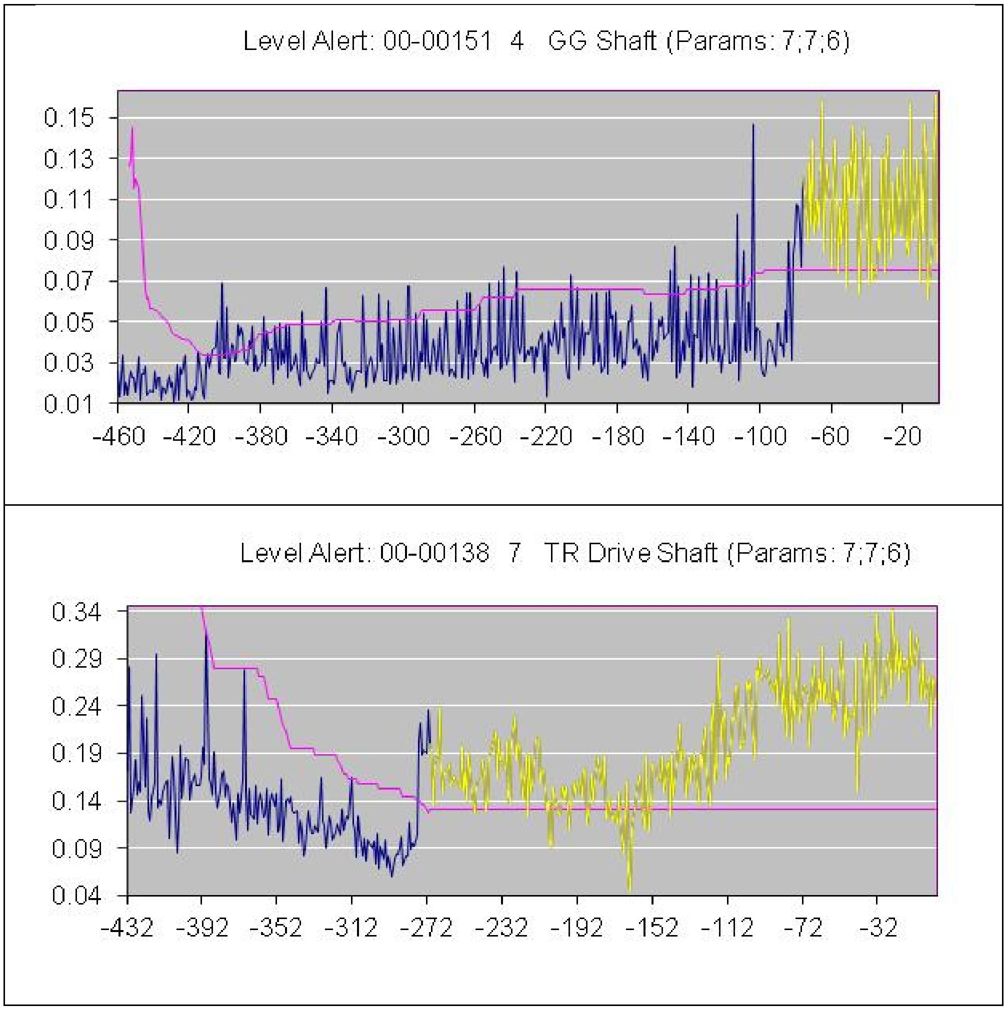

Figure 2. Example Primary Threshold Use

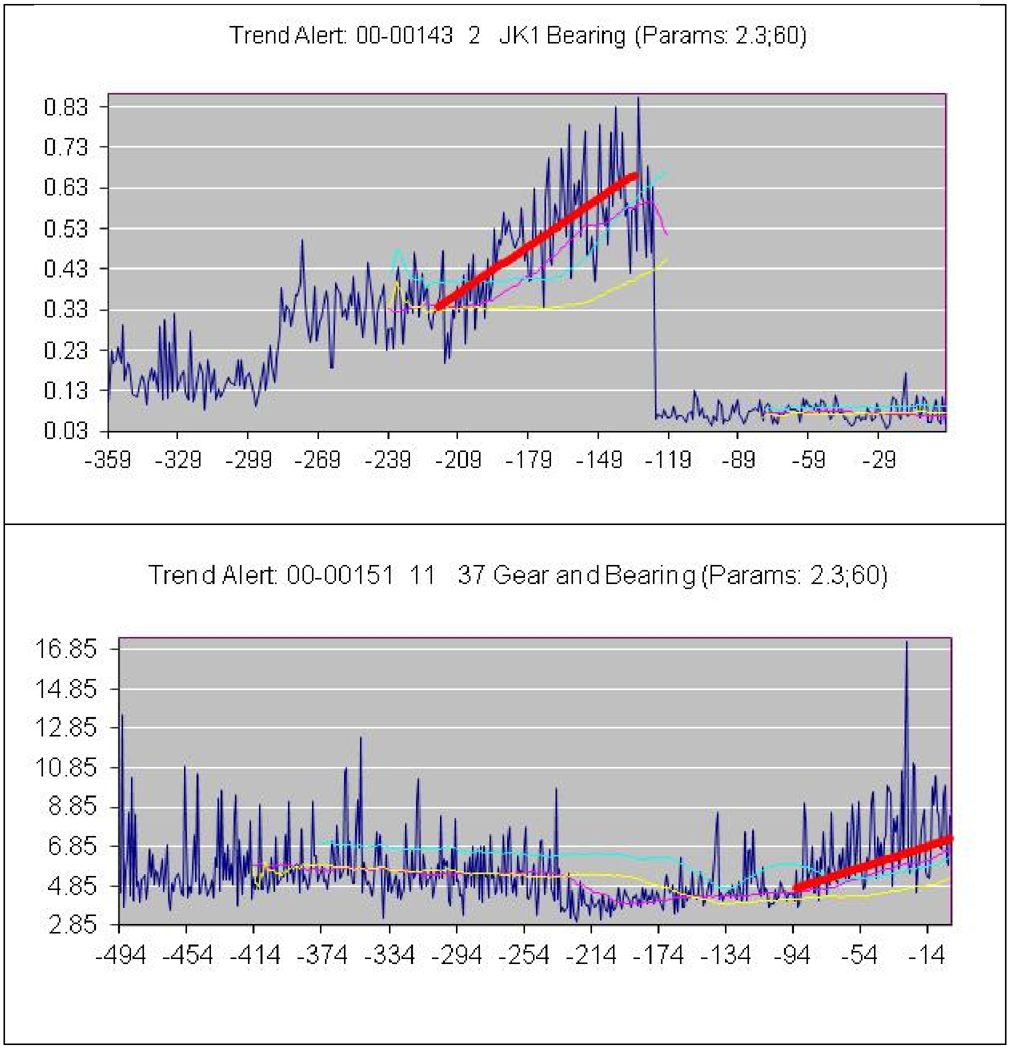

Figure 3. Example Trends

Figure 4 is typical of the conditions that produce the FPs reported in Table 1. The data were unusually correlated, and a large number of the points appeared to be repeated. These data randomly correlate to form wide pulses. The conditions cause both the CFAR and Autotrend processing to generate FPs. If this were typical data associated with a CI type, component, or sensor, the set parameters could be adjusted to compensate for the correlation. These data types occur sporadically in the data set, so the FPs that result are an irreducible component of the performance of the system.

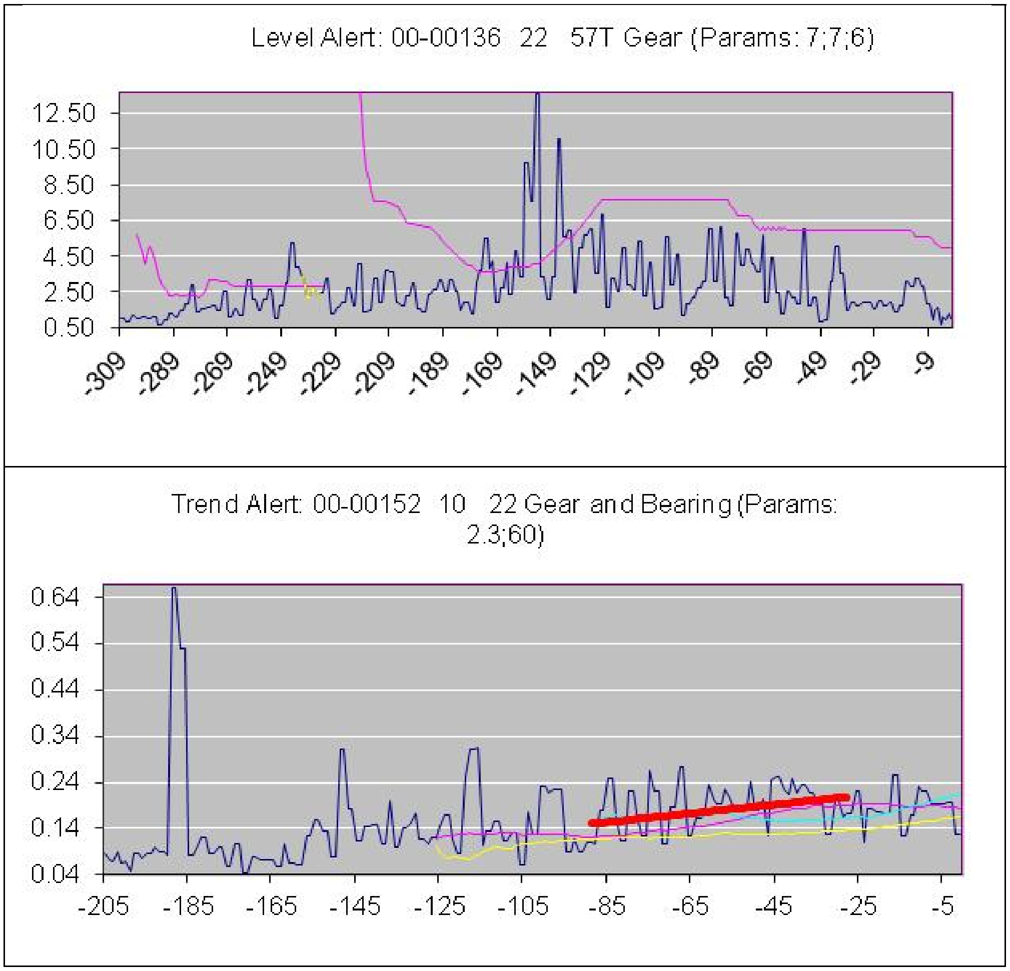

Figure 4. Typical False Alarm Situations

The invalid data reported in Table 1 was of the form shown in Figure 5.

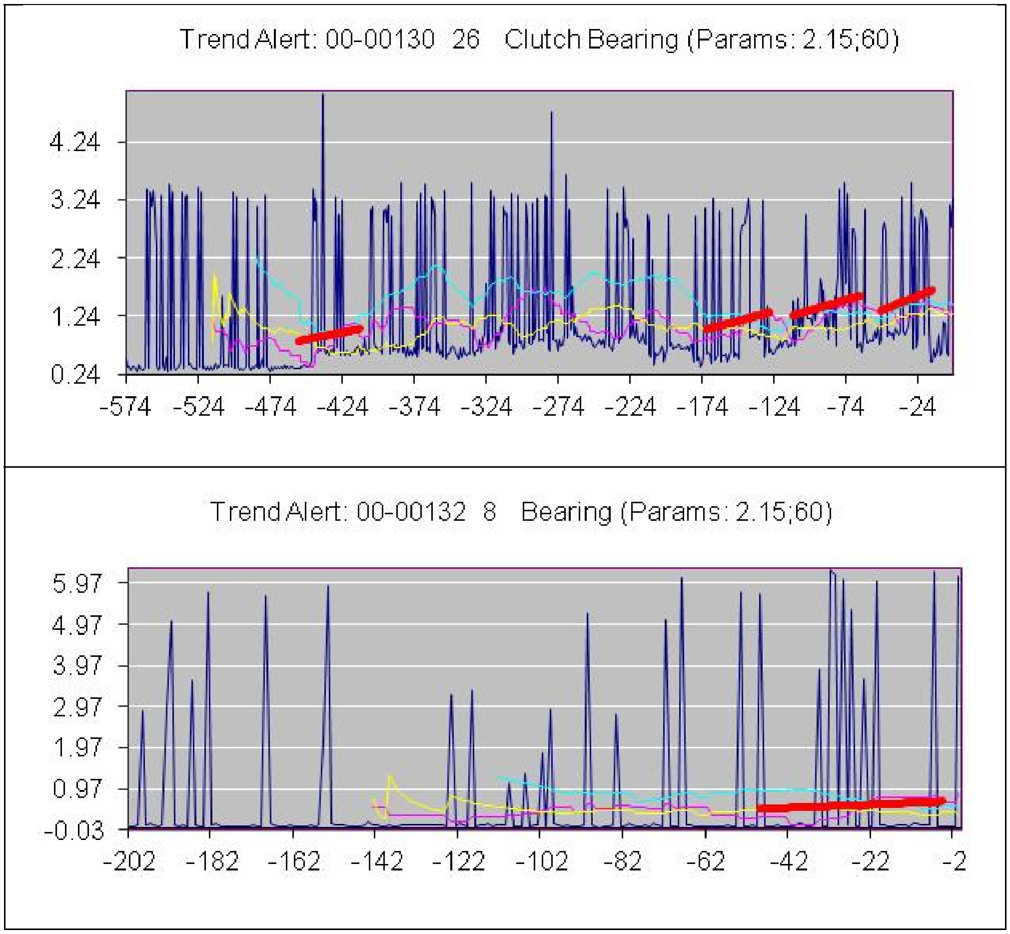

Figure 5. Example of Invalid Data

When tones correlate (such as those in the previous figures), they generate FPs in the Autotrend data. This behavior is dominated by data from the Auxiliary Power Unit (APU), which is found only sporadically in any other module. AMRDEC agreed to investigate the data quality of the APU and also agreed that these data sets were not to be included in the performance analysis. The Parameter Allocation Table (PAT) in the CFAR Autotrend was used to switch off the processing from this source.

The control parameters for the CFAR Autotrend parameters were reviewed to optimize the TP and FP metrics.

There were a large number of multiple alerts on the Autotrend in particular, as shown in Figure 6. The inflated number of true alerts indicated that the box car length (the number of points that constitute a trend by the diagnostics process) was too short.

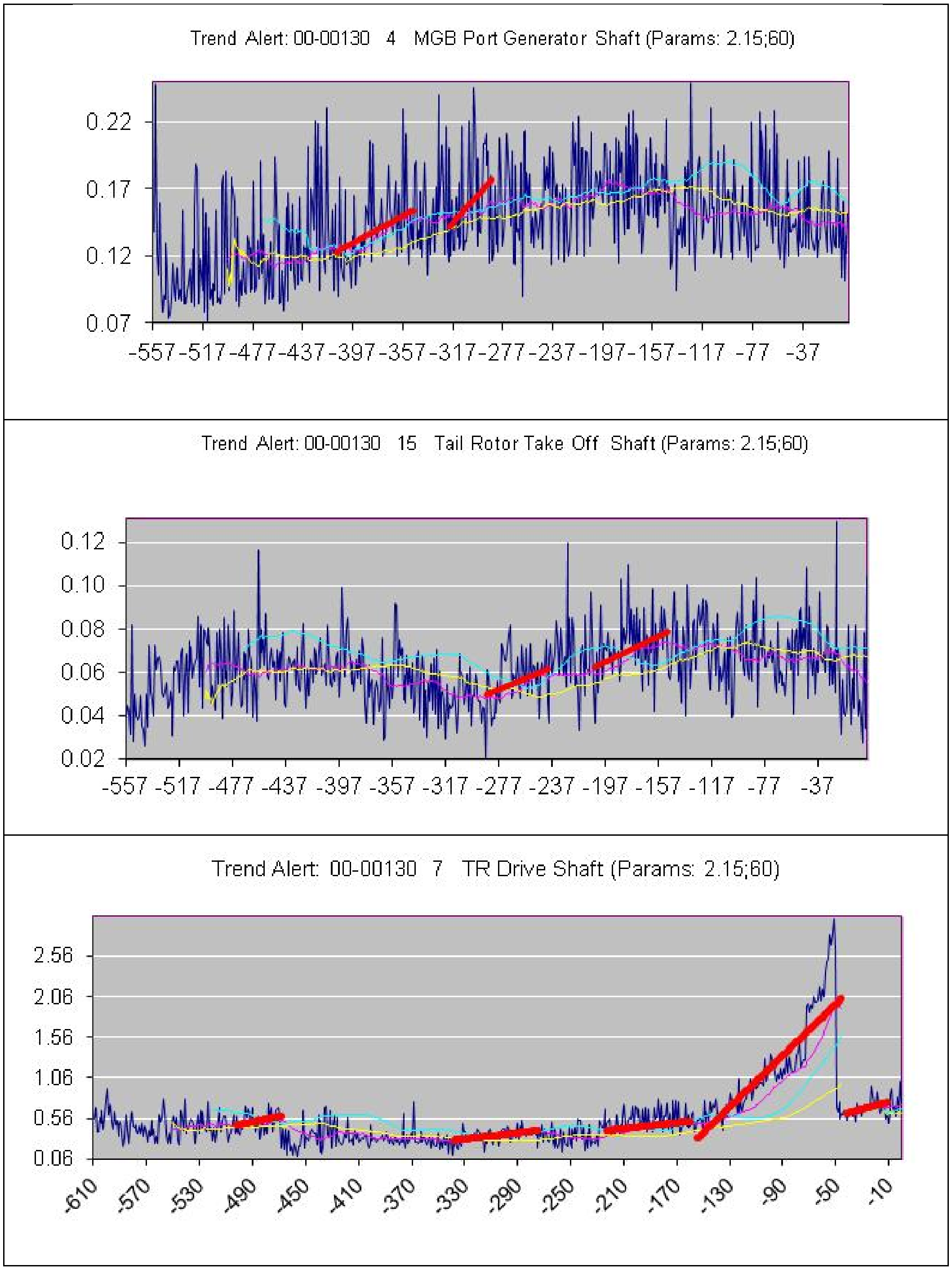

Figure 6. Example of Multiple Trend Detections in the Same Trend

The box-length parameter was increased, as was the TiN parameter, to reduce the number of low rate trends that produced alerts. The MooN parameters were increased to remove trends that were not sustained, therefore removing the spurious alerts. There were a number of trends that occurred as a result of level changes not alerted by the CFAR processing, as shown in Figure 7.

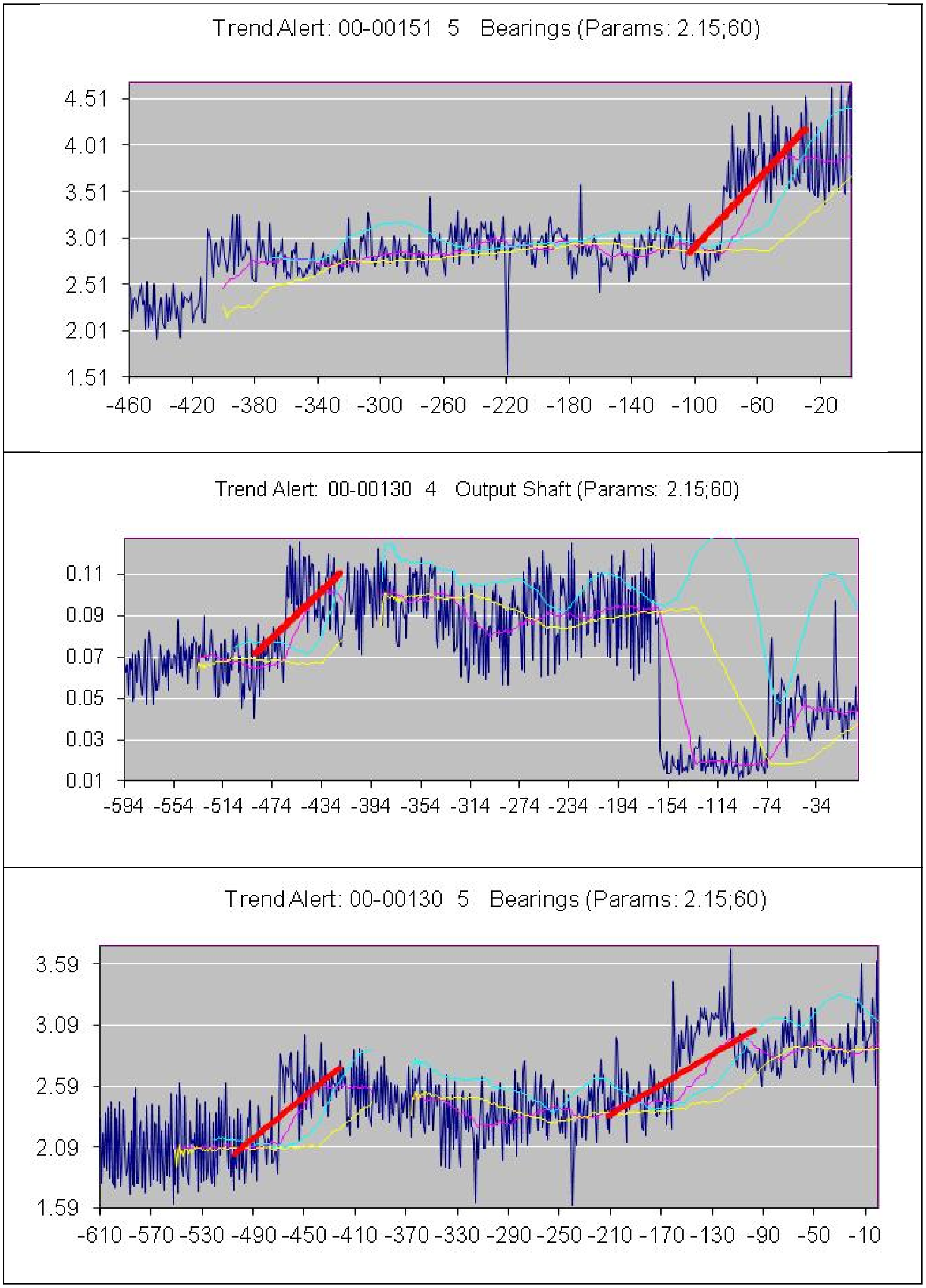

Figure 7. Example of Trends that Should Be Level Alerts

This effect is caused by the primary threshold in the CFAR processing being too high. To correct this, the Primary Threshold's PTE rate was increased to make it more sensitive to the level changes. The secondary processing MooN was maintained to keep the FAR in excess of 1 in 100,000.

The value at which to report a detection of a level change is set by a conservatism factor. Any changes made to the conservatism factor parameter caused more TP alerts to be lost than the reduction of FP alerts achieved, so it was maintained at 1. The discontinuity or step detector conservatism level was adjusted to remove ambiguities between step and level alerts.

The resulting changes in the parameter sets with the reasons for the changes are shown in Tables 2 and 3.

Table 2. Before and After Parameters for Autotrend

Parameter Name	Separation	Maximum Car Length	Box Length	TiN Tolerance (%)	M	N
Kptest1	2.15	60	30	20	2	3
	Increased to reduce spurious trends		Increased to reduce number of split trends	Increased to remove low rate trends	Increased to remove spurious trends	Increased to remove spurious trends
kptest2	2.3	60	40	30	3	4

Table 3. Before and After Parameters for CFAR

Parameter Name	Primary Threshold Exceedance (%)	Window Length	Level Conservatism Factor	M	N	Step Conservatism Factor	Step M
kptest1	3	70	1	5	7	15	3
	Increased to increase sensitivity to level changes	Reduced to better track the envelope of the signal			Increased to maintain target FAR	Increased to reduce number of alerts due to pulses in data set	
kptest4	7	60	1	6	7	22	3

These modifications to the control parameters resulted in the performance as shown in Table 4.

Table 4. Final Results After Parameter Adjustments

Metric	Old	New
TP	480	367
FP	123	33
Uncertain	165	11
Invalid Data	54	29
Total	822	440

The uncertain alerts were compared to DA Form 2410 data to determine which were true alerts and which were false alerts. Eleven alerts could not be resolved.

The resulting 33 FP alerts are randomly distributed across module, CI type, aircraft, and sensor and are, therefore, considered an irreducible residual FP rate.

G. Results

The results of the processing, as used for the analysis, are contained in the Excel Workbook Evaluation data Version 1.2.3.xls [7]. There are three worksheets: MSPU data, CFAR discovered data, and uncertain data. The uncertain data were the borderline CFAR Autotrend alerts that required DA Form 2410 evaluation in order to determine whether they were true or false alerts. These results were achieved with a single CFAR and Autotrend parameter set.

H. MSPU Detected Defects

The evaluation MSPU data set consisted of 20 examples. Of the 20, 11 were either alerted on the component's installation or insufficient data was provided. The CFAR Autotrend technique identifies the relative changes in the data, and since an installed defect does not produce a relative change in the data, absolute techniques will still be required to detect these defects. Therefore, they were excluded from the analysis. The remaining nine cases produced the metrics as shown in Table 5.

Table 5. ADS-79 Metrics Summary for Fixed Thresholds

Metric	Fixed Thresholds	CFAR Autotrend	Ground Truth
TP	7	8	8
FP	1	0	
TN		1	1
FN	1	0	

Current operational procedures affirm that a single CI is acceptable to produce a fault indication. Of the CFAR Autotrend alerts, only one alert was a single CI alert. The remaining alerts were multi-CI, which may improve the accuracy, indentifiability, and separability of the diagnostic processing.

The CFAR identified two defects that were not detected by the fixed thresholds, which is evidence of greater sensitivity to defects.

The timing of the alerts for CFAR were, on average (with Standard Deviations), 11(16) points or 24 (30) days earlier than the fixed threshold alerts, and the trend detections were 35 (16) points or 34 (5) days in advance of the fixed threshold date. The large standard deviation in the "days" sample interval is due to the random occurrence of aircraft calendar downtime in the evaluation data set. The downtimes also have a large variance. It would improve the variance if the metric were changed to flight hours. Such a conversion of metrics is outside the scope of this evaluation.

There is some evidence of a useful prognostics capability provided that Remaining Useful Life (RUL) data can be reliably estimated from the indicators, but this is beyond the scope of this study.

I. CFAR Autotrend Discovered Defects

There were 28 events identified by the CFAR Autotrend that indicated a possible defect. All but four detections were confirmed by the DA Form 2410 data; these four cases represent a level of uncertainty in the performance analysis.

The performance analysis produced the following Key Performance Indicators (KPIs) as shown in Table 6.

Table 6. ADS-79 Metrics for CFAR Autotrend Using DA Form 2410 data

Metric	Fixed Threshold	CFAR Autotrend
TP	2	24
FP	0	0
FN	22	0

The majority of the fixed threshold FNs discovered by the CFAR occured because the fixed thresholds were set artificially high to ensure an acceptable FP rate. Because this is a fielded system, these defects were not alerted to maintenance; therefore, it is considered reasonable that they are reported as fixed threshold FNs.

Combining the two sets of results with the uncertainty caused by the undetermined detections produces a best case as shown in Table 7.

Table 7. Best- and Worst-Case Comparison of CFAR Autotrend ADS-79 Metrics

Metric	Fixed Threshold	CFAR Autotrend Best Case	CFAR Autotrend Worst Case
TP	9	37	33
FP	1	0	4
FN	27	0	0

The FN rate for CFAR is idealistic. The total population of defects has been discovered by the two alert detection technologies, not selected from an independent ground truth set of defects. This analysis is sufficient to compare the two techniques, but it does not provide the absolute performance measure for the CFAR Autotrend FN rate.

Overall, there were 411 CFAR detections—a very large number. The data set has an artificially large number of events embedded in it, and each event triggered multiple detections in the CIs in the CFAR Autotrend processing. These detections were analyzed as true or false. There were 11 detections that could not be resolved, which represents a level of uncertainty in the analysis. The best- and worst-case data are shown in Table 8.

Table 8. Best- and Worst-Case Comparison for CFAR ADS-79 Metrics

Metric	Best Case	Worst Case
TP	378	367
FP	5	33
Percent of FP	8	11

The FPs are within the target of 10 percent in the best case, but they are slightly adrift in the worst case. Given that most of the uncertain CFAR Autotrend detections have been resolved as true so far, it is unlikely that the worst case would materialize.

The timelines of the CFAR Autotrend, when compared to fixed threshold detections, are shown in Table 9.

Table 9. CFAR and Autotrend Detection as a Function of Time

	CFAR	**Autotrend**
Data Points	-17	-18
Time (days)	-27	-15

The inconsistent distribution of time versus points is due to the large intervals of non-flying times that are randomly distributed through the data set.

The number of alerts in the CFAR Autotrend detection relating to a single maintenance event is shown in Table 10.

Table 10. Number of Alerts per Maintenance Event

Number of Alerts/Event	1	2-3	4-10	10+
Number of Events	10	12	13	2

From Table 10, 73 percent of maintenance events resulted in more than one alert being generated. These results correlate to the number of CIs used on each component. If there is a rich set of CIs, there will be a rich set of alerts that could support the development of robust health indicators. It is noted that CIs are not allocated in a constant way across the components in the evaluation database. Consistency in the application of the technology will be required to provide constant health indicators.

J. Analysis of Results

PD for the CFAR Autotrend based on the valid test cases was 100 percent. Test cases included a number of faults present on installation. CFAR Autotrend is designed to identify a relative change in the signal level and is not a suitable technology for detecting installed faults.

The results clearly demonstrate that the ADS-79 False Alert target of 10 percent can be met. This ADS-79 performance metric has been achieved. The known false alert in the test cases was not alerted by CFAR Autotrend.

The automatic production of thresholds resulted in a large number of defect discoveries in the data set. This was due to the MSPU gear thresholds not being set. The MSPU is technology in service, and therefore it is reasonable to say that these discoveries amount to the FN rate. Due to the design of the evaluation—all faults were discovered by one or the other of the techniques—there were no identified FNs for the CFAR Autotrend. To identify the true FN rate a test case set needs to be constructed from the DA Form 2410 records without reference to the defect detection source, and the performance of alert technology must be evaluated.

The total number of identified defects was 33, a reasonable sample for determining the relative detection performance between the techniques.

There is evidence of prognostics capability as shown in Figure 8.

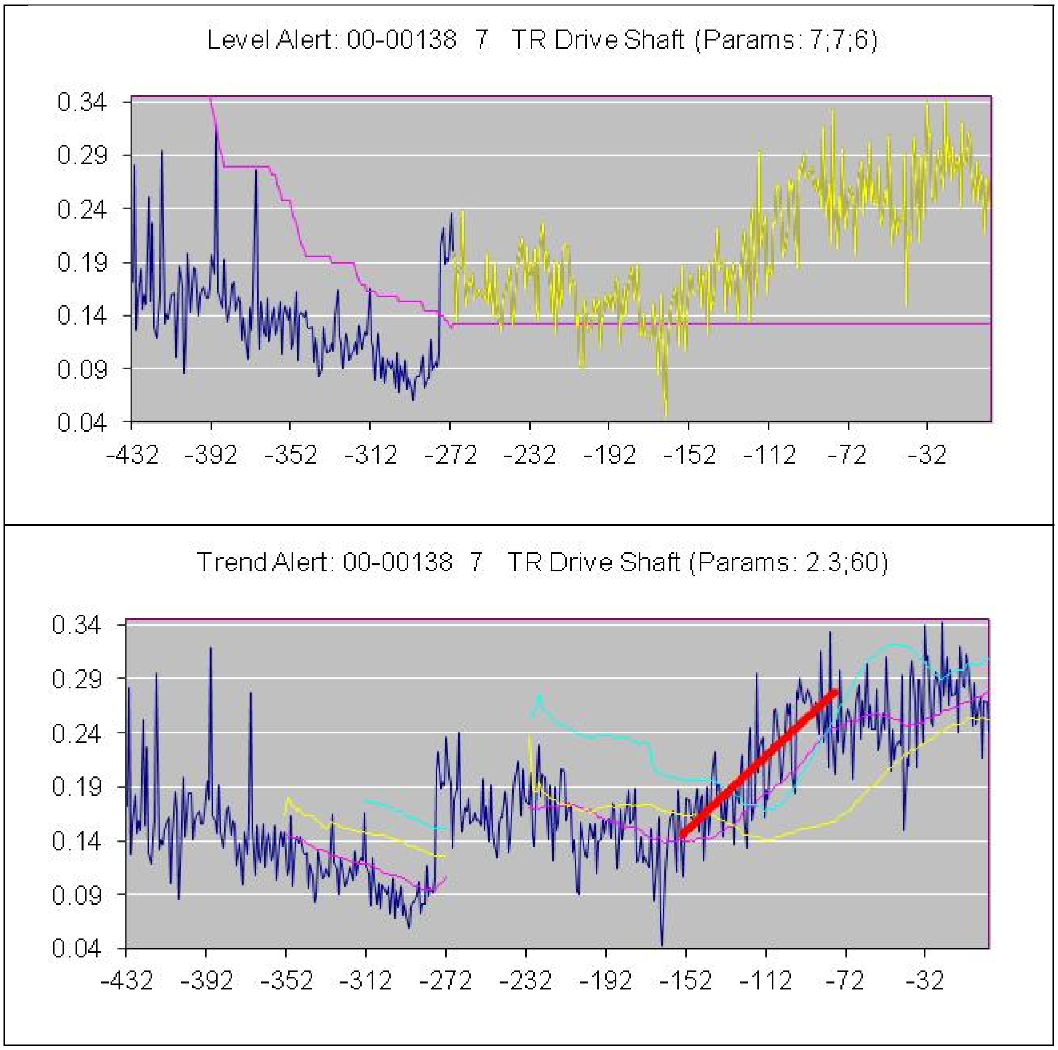

Figure 8. Demonstration of Prognostic Capability

From the plots in Figure 8, it can be seen that a clear level detection did not result in immediate maintenance intervention. There is a clear trend detected following the level alert. This results in a change in level to a point where the component was probably removed, which represents a clear prognostic opportunity. In this circumstance, what would be the criteria for removing the component?

There are a large number of double step level changes as shown in Figure 9. Some ambiguity exists because the initial step may be either the incipient defect or the installation of a new component. There is a need for a reset on the installation feature in the system to capture installation events and prevent this ambiguity; otherwise, using this data as a prognostics alert would not be possible.

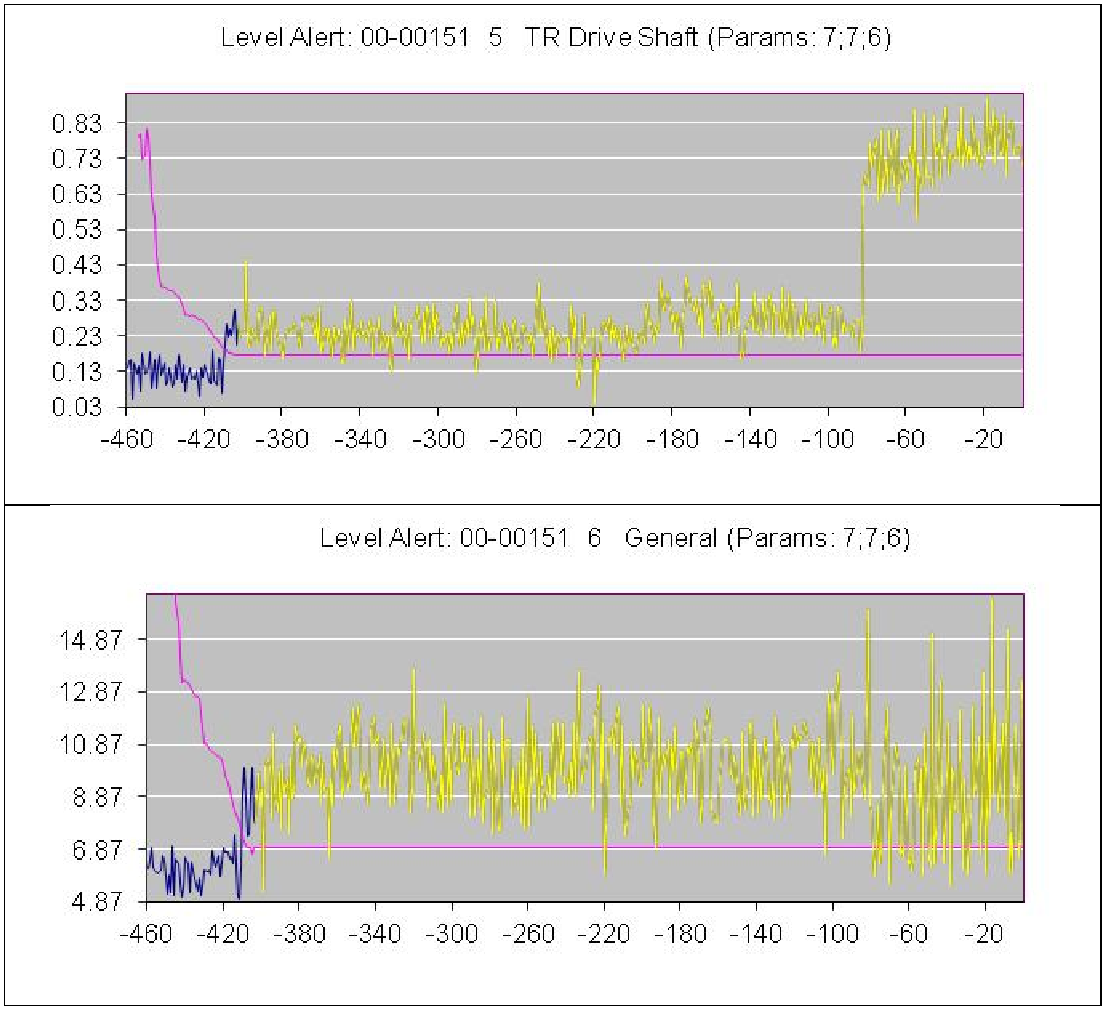

Figure 9. Double Step Example

K. Independent Validation

Apart from the primary evaluation, AMRDEC's Aviation Engineering Directorate (AED) Aeromechanics Division further performed an independent evaluation of the features and performance of the Humaware software. This evaluation examined the functionality and simplicity of setting the various CFAR Autotrend parameters for the purpose of optimizing the results. The evaluation also extended the test set of data to include multiple new data sets containing known component failures. CFAR Autotrend was able to accurately detect 100 percent of the known failures, including one failure that the fixed thresholds were unable to detect. A summary is shown in Table 11.

Table 11. Independent Evaluation Summary of Ground Truth Data

Metric	Fixed Threshold	CFAR
TP	8.5	10
FP	0	0
FN	1	0

Including the known failures, CFAR provided 135 alerts of possible events, whether they were simply maintenance events or impending component failures. By researching the DA Form 2410 reports for the appropriate aircraft, AMRDEC was able to successfully link 76 of the alerts to known maintenance events. There were 58 alerts that could not be successfully correlated to recorded maintenance events; however, many of these were related to non-2410 recorded components, such as drive shaft and tail rotor imbalances. This is summarized in Table 12.

Table 12. Total CFAR Detections

Metric	CFAR
TP	76
FP	1
Unknown	58
Total	135

In terms of events, the performance is shown in Table 13.

Table 13. CFAR Performance

Metric	CFAR
TP	22
FP	1
Unknown	12
Total	35

Much of the work needed to optimize the parameters was performed during the primary evaluation, and the results were used as the base parameter set for the independent validation. AMRDEC experimented slightly with tweaking the parameters and was able to obtain a better knowledge of how such methods affect the resulting alerts. For whatever reason, the Autotrend portion of the software did not function properly on the independent computer so there are no results, either positive or negative, to show for it in this independent evaluation. Due to time constraints, AMRDEC was unable to fully explore the use of setting bull's-eye parameters in CFAR. The function was explored during the initial training of the software, however, and would likely play a vital role in many, if not all, of the CIs were this software to be utilized in the near future.

L. Findings

The principal findings from the evaluation program are that CFAR Autotrend—

- Exceeds the fixed threshold detection accuracy.
- Provides a significantly earlier detection than the fixed thresholds.
- Detects maintenance events (material faults) that are not identified by fixed thresholds.
- Is ready for use as an engineering tool in its current form.

III. RECOMMENDATIONS

The assessment finding is that the technology is ready for the next stage of development. This section aims to identify what these steps are. There are three areas of development. The first is to identify the steps needed to develop an in-service CFAR Autotrend alert detection capability. The second is to develop and execute the service delivery. The third is to identify the improvements in diagnostics and prognostics performance made possible by the technology.

A. Develop In-Service Capability

The following work items represent the issues that need to be addressed by AMRDEC to develop an in-service CFAR Autotrend capability:

- Full verification for all relevant CI data sets for HUMS equipped fleets. *(This is required to ensure that the performance reported in the assessment is valid for the whole fleet data and that the parameters are correctly set and allocated to the CI data types.)*
- Verify the levels of conservatism to be applied to the setup parameters to minimize the No Fault Found (NFF) rate and not compromise the TP and FN rates. *(The assessment shows that the processing can be too sensitive to defects, raising the prospect of increasing the NFF rate and costing useful life. The CFAR Autotrend setup parameters can be backed off to reduce sensitivity.)*
- Assessment for other data sets, such as engine Health Indication Test (HIT) check trending. *(There are other data sets being recorded in the HUMS, engine performance, and usage that could benefit from the use of the technology. This should be evaluated before fielding.)*
- Verify integration with existing red static alert thresholds in the CFAR Autotrend using the Binary or Bull's-eye Alert feature. *(It will be necessary to validate the performance of the unified system of fixed "red" alerts combined with the dynamic "yellow" warning alerts.)*
- Revise the training and doctrine for the use of trend-based alerts by personnel utilizing the system. *(Having trend alerts available is a new capability; correct usage needs to be determined before fielding.)*
- Validate the software functionality and the operational interfaces for the control and processing of the CI data. *(The current software is configured for application development work and verifying performance. The in-service application will require different functionality for data management, that is, the processing of data in slices as they are downloaded from the aircraft. The data output formats for diagnostics and prognostics displays and applications need to be implemented. All of this functionality is outside the proprietary package and is implemented in the "connectors." This functionality will need to be developed and validated.)*
- Develop a maintenance action reset facility. *(This has been identified as a feature necessary to prevent maintenance action from being alerted as defects.)*

- (Optional) Improve installed defect detection capability. *(Investigate the use of trends to improve performance of installed defect detection performance.)*
- Develop DO 178 B (Level D) certifiable version of core CFAR Autotrend processing. *(The certification standards applied to the software need to be consistent with the other processes in the diagnostics data flow in order to grant maintenance credits.)*

B. Service Delivery

The service delivery includes all the program requirements necessary to field the capability.

This will be an independent activity for each DSC type.

CFAR Autotrend processing needs to be applied where the CI data is first reviewed in order to gain the performance benefits. One may argue that this should be done on either the aircraft system or on the ground stations (so that all users see the same alerts). For the purpose of this work breakdown, it is assumed to be a ground station application. The architecture is for three software modules—an Input Connector, an Output Connector, and a standard CFAR Autotrend processing module. The following applies for each application:

- Develop interface control documents, functional specifications, test and fielding plans.
- Develop Input Connector to support access and management of data inputs.
- Develop Output Connector to support interfaces with diagnostics screens and processes.
- Integrate and test the three modules.
- Integrate in the hardware. *(This will require DO-178B (level D) recertification of the entire process in the ground station.)*
- Implement the existing red static alert thresholds in the CFAR Autotrend using the Binary or Bull's-eye Alert feature.
- Validate upgrade in ground stations.
- Modify handbooks to provide operating procedures for trend alerts.
- Execute fielding plan. *(This is a data-driven process so there will be the need to develop a system for AMRDEC to monitor and manage data quality.)*

C. Diagnostic Processing Improvement

The assessment program demonstrated that:

- The CFAR Autotrend technology can provide a tool for data discovery that can support the Verification and Validation (V&V) of diagnostics and possibly prognostics processes.
- The alerts have attributes that can improve specificity of the diagnostics. This is necessary to support the certification of maintenance credits.
- The alerts have demonstrated that a significant RUL can be achieved. For prognostics to be certified, this must be verified as being a safe life remaining.

The following work items relate to developing a diagnostics and prognostics capability based on using the alert detection capability of CFAR Autotrend:

- Diagnostic Development Integration into engineering support systems. *(Develop the input and output connectors for the AMRDEC installation to be applied to data warehouse and other data repositories, and to report results to other analysis packages.)*
- Reevaluate the extant CI performance review to determine if CFAR Autotrend technology improves the AMRDEC batting averages.
- Use CFAR Autotrend to discover the defects in Data Warehouse data, and develop Golden Database to support diagnostic development V&V.
- Statistically evaluate level alerts from the Golden Database to determine if re-basing levels to the primary threshold values can improve diagnostic discrimination of defects that compromise airworthiness criteria from acceptable wear.
- Statistically evaluate if box trend rates from the Autotrend processing can improve diagnostic discrimination of defects that compromise airworthiness criteria from acceptable wear.
- Develop Bayesian probabilities and combinational rules for Health Indicators utilizing the results of 3.3.1 and 3.3.2 to develop criteria for safe RUL. *(This will require the allocation of CI types to defects to be rationalized and applied more uniformly in order that the Bayesian probabilities can be calculated.)*
- Modify CFAR Autotrend alert detector parameters to implement the improved diagnostics and prognostics alert capabilities.
- Verify performance on Golden Database.
- Develop, as appropriate, CI diagnostics knowledge base to include heuristic diagnostics capabilities from sources other than the DSC.
- Develop a Service Delivery Plan.

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5. Wade, Daniel; Antolick, Lance; Branning, Jeremy; and Dempsey, Paula, “Evaluation of Gear Condition Indicator Performance on Rotorcraft Fleet,” American Helicopter Society Forum, Phoenix, AZ, 2010.

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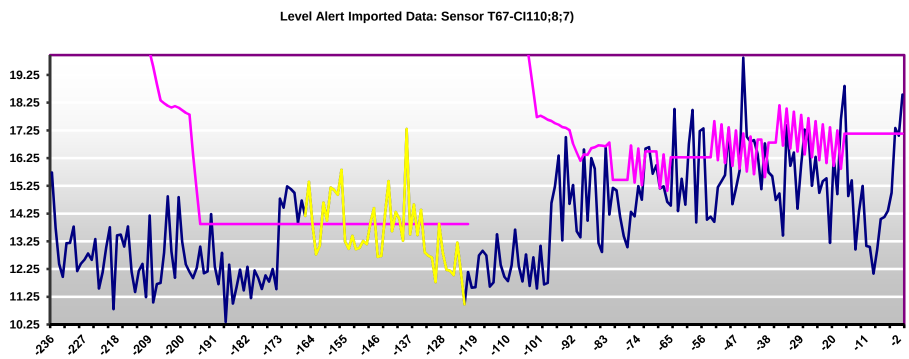
LIST OF ACRONYMS AND ABBREVIATIONS

AMRDEC	Aviation and Missile Research, Development, and Engineering Center
APU	Auxiliary Power Unit
CFAR	Constant False Alarm Rate
CI	Condition Indicator
CSV	Comma-Separated Value
DAD	Detection Algorithm Development
DSC	Digital Source Collector
FAR	False Alarm Rate
FN	False Negative
FP	False Positive
HIT	Health Indication Test
HUMS	Health and Usage Monitoring System
ID	Identity
KPI	Key Performance Indicator
MooN	M-out-of-N
MSPU	Modernized Signal Processor Unit
NFF	No Fault Found
PAT	Parameter Allocation Table
PD	Probability of Detection
PTE	Primary Threshold Exceedance
RUL	Remaining Useful Life
TiN	Trend in Noise
TN	True Negative
TP	True Positive
UK	United Kingdom
V&V	Verification and Validation

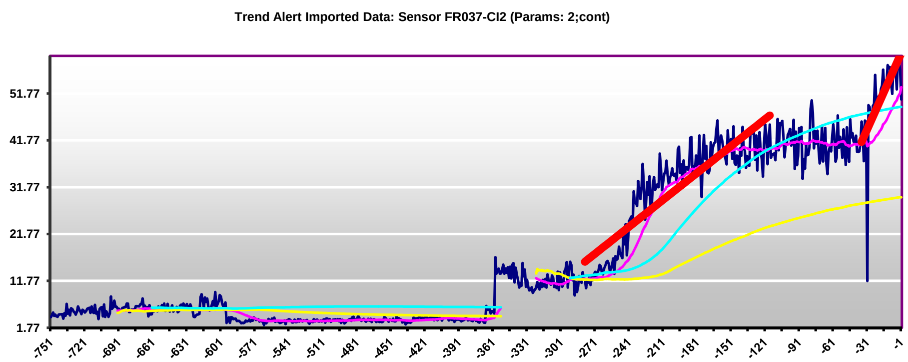
KEY TO CHARTS

The results of the Constant False Alarm Rate (CFAR) Autotrend processing are displayed as graphical reports.

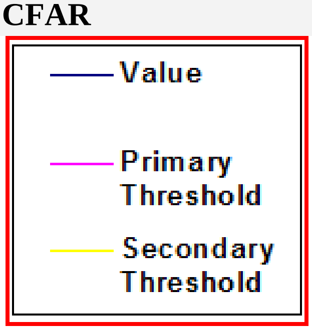
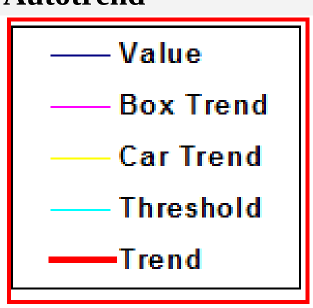
CFAR Processing



Autotrend Processing

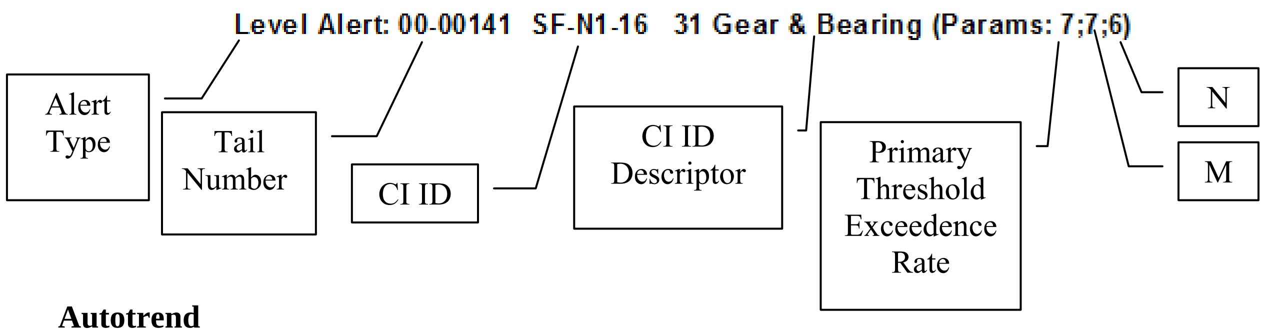


A key for these reports is shown below.

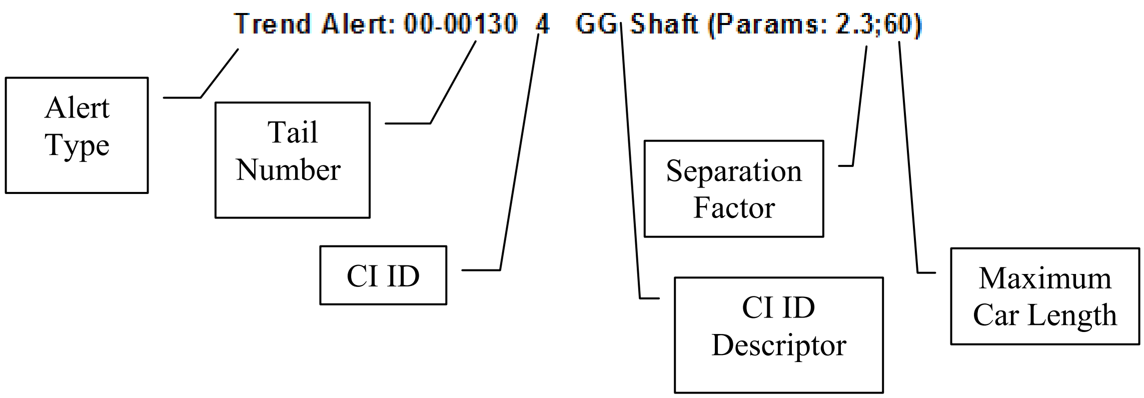
CFAR	**Autotrend**
	

NOTE: For the CFAR, the Secondary Threshold is not a separate plot. The Secondary Threshold identifies where the secondary processing criterion has been satisfied and therefore an alert detected. This "Threshold" is indicated by plotting the data steam values in yellow.

Chart Headers
CFAR



Autotrend



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